

# **Modeling the Formation and Offshore Transport of Dense Water from High-Latitude Coastal Polynyas**

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## **LONG-TERM GOALS**

Our long-term goal is to understand the role that dense water, formed on high-latitude continental shelves, plays in the thermohaline circulation of the Arctic Ocean and the maintenance of the mean hydrographic structure of the deep Arctic basins, e.g. the upper halocline.

## **OBJECTIVES**

Our immediate objective is to improve our basic understanding and ability to predict (1) the formation and offshore transport of dense shelf waters formed beneath high-latitude coastal polynyas and (2) the pathways by which dense shelf waters enter the deep basins.

## **APPROACH**

Our hypothesis is that dense water, formed beneath coastal polynyas, is transported across the shelf via small-scale (15-25 km) eddies (e.g. Gawarkiewicz and Chapman, 1995; Chapman and Gawarkiewicz, 1997; Chapman, 1999; Gawarkiewicz, 2000). These dense water eddies are capable of moving offshore across the shelf break and into the deep basins where they contribute to the maintenance of the observed thermohaline structure. We have been testing this hypothesis with a combination of (1) process-oriented numerical modeling, (2) analyses of historical observations, and (3) numerical modeling of realistic coastal polynyas.

## **WORK COMPLETED**

(1) A study has been completed of the distribution and interannual variability of dense water production from coastal polynyas on the Chukchi Shelf over the past 20 years (Winsor and Chapman, 2001).

(2) A study of the effects of bottom friction on dense water production in idealized coastal polynyas has been completed and is being prepared for publication.

- (3) A study of the joint roles of ice cover and shelfbreak topography on wind-driven upwelling and downwelling on broad Arctic shelves is nearly completed (Carmack and Chapman, 2001).
- (4) Shelf-basin exchange resulting from the coastal current along the northern Alaska coast, with and without dense-water eddies, has been modeled.
- (5) Historical hydrographic data have been analyzed to examine basic dynamical quantities such as stratification and baroclinic Rossby radii. This is important information for analysis of the stability of currents near the shelf edge.
- (6) A website reporting our primary results has been established (<http://www.whoi.edu/science/PO/arcticgroup/densewater.html>)

## RESULTS

- (1) Dense water formation from coastal polynyas on the Chukchi Shelf has been examined using a primitive-equation model forced by surface fluxes from a time-dependent polynya model for the winter seasons of the 1978-1998 period. The model is forced by both meteorological observations and National Center for Environmental Prediction (NCEP) reanalysis data. During the 21-year period the surface forcing and dense-water production vary by a factor of 2. Interannual variability is high with large differences between successive years in both ice production and dense-water production. Most of this variability can be explained by varying wind fields. Maximum salinities produced rarely exceed 33.5 PSU. Based on moored observations in Bering Strait, we conclude that the interannual variability of the initial salinity is of the same importance as the interannual variability in dense water formation, and thus both are equally important in determining whether or not winter water is dense enough to contribute to the cold halocline layer of the Arctic Ocean. Finally, we find that the derived ice volumes and dense water productions are highly sensitive to the choice of forcing (meteorological vs. NCEP).
- (2) Contrary to a recent publication, bottom friction is shown to have minimal effect on dense water production from a narrow (~10 km wide) coastal polynya. The primary effect is to slow the bottom portion of the polynya rim current, thus reducing the vertical shear and delaying the onset of instabilities. The net result is to delay the approach to equilibrium and, thereby, produce a slightly higher equilibrium density than previously predicted. Offshore flux of dense water is not appreciably affected. Bottom friction effects are more important for wider polynyas because the eddies, once generated, cannot propagate far before decaying away. In this case, an equilibrium density anomaly may not be achieved.
- (3) Summer melt-back of the ice cover away from Arctic coastlines leaves the shelf waters exposed to upwelling and downwelling favorable winds for a brief period. There is great interannual variability in the location of the observed summer ice edge. We have used a primitive-equation numerical model to study the effectiveness of upwelling/downwelling winds on Arctic shelves for different locations of the ice edge. We find that the ice edge acts as a kind of switch for wind-driven exchange between the shelf and basin. That is, when the summer ice edge remains over the shelf (shoreward of the shelfbreak), little or no wind-driven exchange can occur. In contrast, when the ice edge melts back beyond (seaward of) the shelfbreak, wind-driven upwelling can easily draw water from deep within the halocline layer of the deep basin. This potentially provides an important source of heat, salt and

nutrients to the shelves which will vary tremendously on interannual and longer time scales. The results also have important implications for the effects of possible changes in ice cover under scenarios of altered climate.

(4) We have used a primitive-equation numerical model to simulate the fate of the coastal current that is known to flow along the northern coast of Alaska. Results show that the current most likely forms a very narrow and swift boundary jet that squeezes between the coast and Barrow Canyon, following the isobaths around Pt. Barrow and flowing onto the Beaufort Shelf. Virtually no shelf-basin exchange occurs in such a flow. If dense water is formed in a coastal polynya along the northern Alaskan coast, the dense-water eddies are powerful enough to move offshore through the coastal current, where they can descend down Barrow Canyon into the deep Arctic basin. Thus, dense-water eddies can produce dramatic increases in shelf-basin exchange.

5) Historical hydrographic data have been collected for the Chukchi Shelf. The extremely limited coverage precludes quantitative climatological analysis, but is useful for estimating parameters necessary for stability analysis. The primary focus of this was to guide sampling efforts in field observations.

## **IMPACT/APPLICATIONS**

Coastal polynyas represent important regions of dense water production on Arctic shelves. The amount of dense water produced each year depends strongly on the meteorological conditions for that year, producing high interannual variability. This can also lead to large changes in the ice cover during summer, which in turn impacts the effectiveness of surface winds at generating shelf-basin exchange. Our results support the hypothesis that small-scale dense-water eddies carry dense water away from polynyas and can produce significant shelf-basin exchange, even when strong currents would otherwise prevent such exchange.

## **TRANSITIONS**

There are no transitions at this point.

## **RELATED PROJECTS**

We have collaborated with Tom Weingartner (U. of Alaska, Fairbanks) and Thorsten Markus (U. Of Maryland) in the examination of historical observations from the Chukchi Shelf and the realistic modeling of this region. We have worked with Seelye Martin (U. of Washington) to develop a realistic model of the St. Lawrence Island polynya in conjunction with the field program that recently took place there.

## **REFERENCES**

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